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Slow dynamic rupture generated by the interaction among heat, fluid pressure and inelastic porosity change

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We theoretically investigate slow dynamic fault slip in this study. Such study will significantly contribute to the understanding of generation mechanism of slow slip event and low-frequency earthquake. What plays a key role in our study is the consideration of inelastic change of porosity and fluid flow near an earthquake fault embedded in a theromoporoelastic medium. Many researchers tend to assume undrained condition in their studies of dynamic earthquake rupture because they believe that fluid flow rate is negligibly small in comparison to the fault tip propagation velocity. However, the diffusivity of crustal rocks suggests that the fluid flows about a few centimeters during dynamic fault slip [Mase and Smith, 1987]; this flow distance is almost comparable to the thickness of narrow zone in which intense shear deformation is accommodated during dynamic fault slip. Hence, the fluid flow cannot generally be neglected in reasonable simulation of dynamic fault slip.

The porosity is assumed to increase inelastically with increasing fault slip. We have found in a series of our studies that the nondimensional parameter Su controls the process of dynamic earthquake rupture. It has also been shown that the condition that Su is greater than Sc should be satisfied for the majority of earthquakes because only a fraction of remotely applied tectonic stress is released by an individual event if Su is in this range, where Sc is a parameter dependent on material property of the medium. We therefore assume the range that Su is greater than Sc in the present study. The rate of increase in the fault-tip stress intensity with the fault growth is found to be much smaller than expected from classical singular crack model. Hence, the fault growth is vulnerable to slight spatial perturbation of fault strength in our model.

We found in our simulation of spontaneous fault tip growth that the fault tip velocity is significantly dependent on the diffusivity; we observed in some examples that the fault tip extends with velocity 1km/s or less for a while. If the strength is assumed to be homogeneous, the growth turns from slow- into high-speed one sooner or later. However, the strength will be somewhat heterogeneous on actual faults. If such heterogeneous distribution is taken into account, there exists a high possibility that the slow fault growth is arrested before turning into high-speed rupture: note that the fault tip growth is vulnerable to slight spatial perturbation of model parameters in our fault model. Even if the dynamic fault growth is arrested, the fault growth is likely to resume if we assume the fluid flow. In fact, our study shows that the Coulomb failure stress tends to increase with time at the arrested fault tip because of fluid flow. This will trigger the dynamic fault growth and it will be slow dynamic growth at least at the initial stage. The whole rupture process will be complex and composed of many smaller-scale slow dynamic ruptures and it will be recognized as slow dynamic rupture process as a whole.